Master Thesis U.S.E.

Green Bonds as Catalysts for Energy Efficiency[1]

Examining the Impact on Energy-Intensive Industries within the European Union

Niels Swinkels
6255205
n.m.a.swinkels@students.uu.nl

Supervisor: Dr. Mohamad Kaakeh

Second Supervisor: Dr. Lisa Sheenan

Abstract

This thesis examines the impact of first-time green bond issuance on corporate energy efficiency within energy-intensive industries in the European Union. The primary research question investigates how green bonds affect post-issuance energy efficiency metrics compared to non-issuing peers and whether these impacts vary across different industries. Utilizing Propensity Score Matching, Linear Regression, and Difference-in-Differences analyses, the study assesses data from 67 first-time green bond issuers and 117 conventional bond issuers over a ten-year period (2013-2023). The findings reveal that green bond issuances significantly enhance energy efficiency metrics, with notable variations across industries. These results suggest that green bonds are effective tools for promoting energy efficiency and sustainability, highlighting the need for tailored approaches to maximize their impact across diverse industrial sectors.

JEL: Q56, O13, O16

Key words: Green bonds, Energy efficiency, Europe, DID analysis

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Introduction

This thesis explores the impact of green bond issuance on corporate energy efficiency within the European Union's (EU) energy-intensive industries, a critical area for sustainable economic growth and environmental conservation. Enhancing energy efficiency is essential and not merely an objective. Consequently, the EU's Energy Efficiency Directive (European Parliament and Council, 2023) underscores the importance of decoupling energy consumption from economic growth, highlighting the significance and timeliness of this study.

Energy-intensive industries are major contributors to environmental degradation due to their high energy consumption and incur significant costs, which makes them central to sustainability efforts (Griffin, 2016). As a significant player in the global economy, the EU is pivotal in leading the transition from fossil fuel-dependent economies to those favoring renewable energy sources. This shift is essential for reducing electricity demand, lowering greenhouse gas emissions, and mitigating global warming (Bergmann et al., 2017). However, the transition has been slow (Jonek-Kowalska, 2022), underlining the increasing importance of enhancing energy efficiency. Considering this gradual progress, effective financial instruments stimulating sustainability become crucial (Ameli et al., 2021).

Green finance, particularly through the issuance of green bonds, has proven to support sustainable development by financing projects that address climate change and promote environmental sustainability. Studies by Flammer (2021) and Lyon and Montgomery (2015) highlight the green bond market's growth and its vital role in signalling corporate environmental commitment while providing substantial economic benefits. Additionally, Gibson et al. (2020) and Versal & Sholoiko (2022) underscore the capacity of green bonds to mobilize capital for renewable projects, allowing companies to reduce carbon footprints and enhance sustainability.

Despite these positive developments, significant gaps remain in the empirical evidence concerning the direct impact of green bond issuance on corporate energy efficiency within the EU. Zangheri et al. (2019) observe that although some EU member states have made strides towards energy efficiency, the collective progress fell short of the 2020 targets. Moreover, studies by Tan et al. (2022) and Yeow & Ng (2021) underscore green bonds' influence on improving corporate profitability and environmental metrics globally. However, insights into their effectiveness within the EU's unique regulatory context are limited. This research gap is particularly pertinent given the EU's remaining reliance on non-renewable energy sources, necessitating energy-efficient practices to meet environmental targets (Alola, 2019; Statista, 2023). Additionally, it is not yet understood whether improvements in energy efficiency vary across industries, underscoring the importance of investigating the industry-specific impacts of green bonds.

Therefore, this research aims to bridge this gap by investigating two critical questions:

1. How does the issuance of green bonds by corporations in energy-intensive industries within the EU affect their post-issuance energy efficiency metrics compared to their non-issuing peers?
2. Does the impact of green bond issuance on energy efficiency differ across various industries within the EU?

This research aims to significantly contribute to sustainable finance by providing a detailed empirical analysis of how first-time green bond issuance influences corporate energy efficiency within the European Union's energy-intensive industries. Utilizing a dataset covering the period from January 1, 2013, to January 1, 2023, which includes 67 first-time green bond issuers and 117 conventional bond issuers, the study employs Propensity Score Matching (PSM), Linear Regression, and Difference-in-Differences (DID) analyses. These methodological approaches measure the direct impacts of green bonds on energy efficiency and explore how these impacts vary across different sectors. The findings of this research will offer policymakers, investors, and corporate managers practical insights into the effectiveness of green bonds in driving energy management and sustainable practices. This will support informed decisions in adopting and promoting green finance mechanisms, highlighting the role of green bonds in enhancing the sustainability of corporations within the EU.

The structure of the thesis is designed to explore the research questions systematically. It begins with a detailed literature review that contextualizes green bonds and their linkage with energy efficiency in the EU and relevant theoretical frameworks. This is followed by the hypothesis development section, where two hypotheses are formulated based on identified gaps in existing research. The data and methodology section then outlines the data collection process and details the application of the analyses. Finally, the results section presents the empirical findings, and the discussion and conclusion section interprets these results while acknowledging the study's limitations and suggesting directions for future research.

Literature Review

Green Bonds in Sustainable Finance

The "Climate Awareness Bond" launched by the European Investment Bank in 2007 stands as a watershed moment in the fusion of environmental sustainability with financial mechanisms. This innovative financial instrument, green bonds, was explicitly designed to support various projects to generate renewable energy and conserve biodiversity (Al Mamun et al., 2022; Gabr & Elbannan, 2023; Yeow & Ng, 2021). By 2021, the issuance of corporate green bonds had surged to an impressive $1.1 trillion, marking a significant shift towards supporting the SDGs (Bloomberg, 2024). Despite this remarkable growth, green bonds in 2022 accounted for only 8.85% of the global bond market, underscoring the significant potential for further expansion and the considerable growth achieved since 2020 (European Environmental Agency, 2023).

The absence of a universally accepted definition for "green" projects, as per the Green Bond Principles (GBP), has not hindered the development of various certifications and standards. These initiatives reflect the market's detailed approach to identifying and investing in sustainable projects (Ehlers & Packer, 2017; Talbot, 2017). Despite ongoing debates about their impact on sustainability, green bonds have emerged as a crucial platform for issuers to demonstrate their environmental commitments and meet the growing demand for sustainable investments. They have become vital instruments in environmental risk management and financing projects contributing to long-term sustainability (Karpf & Mandel, 2018; Sartzetakis, 2020).

Green bonds distinguish themselves from traditional financial instruments by committing to allocating their proceeds to environmentally beneficial projects. This commitment is vital for financing renewable energy infrastructure, often requiring significant initial investment but promising long-term, sustainable revenue streams (Gibon et al., 2020; OECD, 2015). Despite the additional costs associated with certification and reporting, issuing green bonds can significantly enhance a company's reputation, attract more institutional investors, improve liquidity, and even boost stock prices upon announcement (Al-Mheiri & Nobanee, 2020; Cioli et al., 2021; Zhou & Cui, 2019). This process underscores the value of transparency and sustainability disclosure in strengthening a company's overall market standing and appealing to socially responsible investors (Kapraun et al., 2021).

Beyond raising capital for eco-friendly initiatives, green bonds are crucial in addressing market imperfections and information asymmetry concerning a firm's environmental commitment. Lyon and Montgomery (2015), along with Lyon and Maxwell (2006), argue that through the issuance of green bonds, companies can signal their dedication to minimizing environmental impact. This signalling theory, as outlined by Connelly et al. (2011), communicates to the market the issuer's commitment to sustainability. Following the assumption that these intentions are genuine, Flammer (2021) anticipates that green bond funds are directed towards energy efficiency, pollution prevention, and green supply chain enhancements. These strategic investments are expected to result in measurable improvements in environmental performance, thereby solidifying the issuer's sustainability credentials.

Theoretical Foundations

Stakeholder Theory

The stakeholder theory underpins the expansion of green bonds by advocating for integrating environmental stewardship with traditional economic objectives. This theory contends that addressing a broader spectrum of stakeholder interests allows corporations to bolster their environmental credentials and build public trust, potentially leading to enhanced financial performance through reduced operational risks (Friedman & Miles, 2002). Barney and Harrison (2020) further elucidate that this strategic alignment with stakeholder interests, including environmental considerations, mitigates risks and capitalizes on opportunities for sustainable growth. This approach signifies a strategic pivot in corporate governance, positing that actual value creation encompasses environmental and social responsibility alongside profit generation (Dong et al., 2022; Freudenreich et al., 2020; Philips et al., 2003; Yu et al., 2021).

Socially Responsible Investment Theory

Building on the stakeholder perspective, the SRI theory accentuates green bonds' pivotal role in sustainable finance by addressing the financial risks of climate change (Oehmke & Opp, 2020). It highlights the necessity of investing in financially viable projects yielding environmental benefits, thereby aligning investment strategies with sustainability goals (Sandberg et al., 2009). Gao et al. (2020) argue that green bonds facilitate capital allocation towards projects like renewable energy, essential for transitioning to a sustainable economy. This strategic investment approach underscores green bonds' potential to form the fundament of a sustainable financial market, accommodating investor objectives with broader environmental targets (Crifo & Mottis, 2016; Tan et al., 2022; Yen et al., 2019).

Porter's Hypothesis

Porter (1991) revolutionizes the perception of environmental regulations by suggesting they can catalyze innovation, leading to productivity gains and improved financial outcomes. This hypothesis posits that environmental challenges, spurred by regulatory pressures or intrinsic motivations to improve GHG emissions and energy efficiency, can translate into competitive advantages. It illustrates that green investments, particularly those channelled through green bonds, comply with environmental mandates and promote innovation, enhancing companies' competitive positioning and financial performance.

Energy Efficiency in the EU

Energy efficiency is essential for sustainable economic growth and environmental protection, impacting everything from household heating to industrial operations. The EU has prioritized separating energy consumption from economic growth to decrease energy imports and enhance business competitiveness. Achieving more with less energy is central to this strategy, as defined by the Energy Efficiency Directive (European Parliament and Council, 2023). Makridou et al. (2016) investigate energy efficiency improvements across 23 EU countries in energy-intensive industries, highlighting the EU's role in promoting sustainable industrial development through energy efficiency. Vogler & Stephan (2007) and Bąk et al. (2022) further confirm the EU's commitment to its policies aiming for sustainable development and energy efficiency.

However, transitioning to more efficient technologies, especially in fossil fuel-dependent sectors, faces technological, financial, and organizational barriers (Sorrell, 2000; Fleiter et al., 2011). Despite promoting renewable energy sources, fossil fuels persist in the region's electricity mix. In 2022, more than 1,000 terawatt-hours were generated from fossil fuels in the EU, with coal-fired electricity production increasing over the past few years due to low renewable output and rising natural gas prices (Statista, 2023). Industrial sectors in the EU, significant energy consumers, show varying sustainable growth rates among member states, emphasizing the need for efficient energy use (Cucchiella et al., 2018). Bicil & Türköz (2021) and Karasek et al. (2023) analyze energy efficiency trends within the EU, identifying drivers of efficiency performance and revealing that the average efficiency of all countries assessed was lower in 2020 than in 2013. This underscores the complex challenges and the persistent reliance on fossil fuels that hinder the transition to a more energy-efficient and environmentally sustainable economy.

Environmental Impact of Green Bonds

Deploying green bonds in renewable energy projects heralds a significant advancement in pursuing environmental sustainability. Gibson et al. (2020) delve into the role of green bonds in mobilizing funds for wind, solar, and hydropower projects, highlighting their critical contribution to reducing GHG emissions and facilitating a transition to a low-carbon economy. Green bonds' capacity to significantly foster renewable energy adoption underscores their importance in global climate change mitigation efforts. Moreover, Versal and Sholoiko (2022) expand the scope of green bond financing to include energy efficiency projects across various sectors. By backing initiatives that enhance energy utilization in buildings, industrial processes, and transportation, green bonds are a versatile tool for curbing energy consumption and emissions.

The issuance of green bonds also plays a pivotal role in influencing corporate environmental and CSR outcomes. Flammer (2021) demonstrates how green bonds contribute to notable improvements in corporate environmental ratings and a significant reduction in CO2 emissions, affirming their effectiveness in climate finance. Similarly, Sebastiani (2019) observes a decrease in CO2 emissions following the issuance of the first green bond by companies in the energy and utilities sector, thereby validating the positive environmental impact of green bonds. Alonso-Conde et al. (2020) and Reboredo (2018) reveal that green bonds boost environmental performance and attract long-term, eco-conscious investors, providing broader financial benefits.

Additional research provides insights into the broader impacts of green bonds on the corporate landscape. Gilchrist et al. (2021) and Fatica et al. (2020) point out the benefits to shareholder value and the tangible reductions in carbon intensity among green bond issuers, particularly post-Paris Agreement and for bonds subjected to external reviews. Zhou et al. (2019) link green bond issuance to improvements in stock prices, profitability, and innovation within Chinese listed firms, suggesting green bonds as a catalyst for sustainable corporate growth. Rao et al. (2022) and Wu et al. (2022) further argue that green bonds encourage green innovation, enhancing environmental performance across industries and contributing to the sustainability agenda.

Nonetheless, the effective implementation of green bond-financed projects faces numerous challenges. Tu & Rasoulinezhad (2021) and Azhgaliyeva, Kapoor, and Liu (2020) discuss the economic and societal obstacles that can detract from the potential benefits of green financing. These complexities underscore the need for a nuanced understanding of green financing's impact, advocating for a comprehensive policy framework that ensures alignment with SDGs and mitigates any adverse effects on environmental and social responsibility (Sinha et al., 2021).

Financial Implications of Green Bonds

Green bonds represent a pivotal shift in corporate financial strategies, aligning investments with environmental sustainability. These bonds finance projects with significant environmental benefits, like renewable energy and energy efficiency improvements, which are vital in reducing greenhouse gas emissions and fostering sustainable corporate practices.

Studies such as those by Ley (2017) and Flammer (2021) have demonstrated that green bonds positively impact financial metrics like return on assets (ROA) and Tobin'sTobin's Q ratio, indicating market approval and rewards for sustainable corporate actions, especially in environmentally sensitive sectors. Moreover, further research by Gianfrate et al. (2019) and Wang et al. (2022) found that strong ESG practices associated with green bond issuance led to favourable stock market reactions and enhanced financial outcomes. Moreover, empirical research aligns with the Porter Hypothesis, suggesting a positive correlation between a firm's environmental and financial performance—enhanced by lower emissions and increased energy efficiency. Orlitzky et al. (2003) confirm this correlation across various studies, strengthening the case for the dual benefits of green investments. Additionally, green bonds have been crucial in funding energy efficiency projects, contributing to operational efficiencies and improved financial indicators like gross profit margins and ROA, as noted by Tu & Rasoulinezhad (2021) and Zhou and Chui (2019).

Despite these advantages, there remains to be debate on whether green bonds offer better financial returns than traditional bonds. Maltais and Nykvist (2020) suggest that financial returns from green bonds are comparable with conventional bonds, with their environmental impact being their main appeal. This perspective complements the cautious stance of financial institutions towards green financing due to perceived risks and possibly lower returns (Sachs et al., 2019).

Hypotheses Development

Amid the expanding literature on green bonds, their intersection with environmental sustainability and corporate financing emerges an intricate narrative that underscores the multifaceted role of green bonds. Studies by Tan et al. (2022) and Yeow & Ng (2021) have foundationally understood how green bond issuances influence corporate performance globally, highlighting their potential to foster a green recovery by improving profitability and environmental metrics. This narrative is further enriched by Tang and Zhang (2020), who illustrate the positive impact of green bond announcements on shareholder value, signalling market approval and potential financial growth for issuers.

Specific research on energy efficiency, as detailed by Tu & Rasoulinezhad (2021) and Zhao et al. (2022), positions green bonds as crucial for funding advancements in this area. Their research suggests a direct correlation between enhanced energy management practices and improved corporate financial outcomes, particularly in energy-intensive sectors. The research by Fan et al. (2017) further underscores the importance of energy efficiency, specifically within energy-intensive sectors, by demonstrating its positive impact on financial performance. Although their study excludes green bonds, it highlights the significant benefits that improved energy management practices can offer to industries where energy consumption is notably high.

Despite these insights, the influence of green bonds at the corporate level within the EU, a region pioneering in sustainability and green finance, still needs to be explored. While extensive, the existing body of research often adopts a global perspective or focuses on regions outside the EU, leaving a gap in understanding the specific corporate and industry-level impacts within the EU context.

Li et al. (2023) and Zhang, Nazar, and Guo (2023) bring the discussion closer to the EU's policy environment, examining its influence on energy efficiency. However, their focus remains on a macro-level assessment of governmental policies, including green bonds, without delving into the corporate and industry-specific effects within the EU.

Given this context, the research landscape presents a compelling opportunity to delve into the nuanced impacts of green bond issuance on corporate energy efficiency within the EU, considering its unique regulatory and market conditions. Therefore, this exploration leads to the development of two focused hypotheses:

Hypothesis 1 (H1): In the EU, energy-intensive corporations that issue green bonds will demonstrate significant improvements in energy efficiency metrics compared to those that do not issue green bonds.

Hypothesis 2 (H2): Energy efficiency varies significantly across industries within the EU.

Data & Methodology

Data Collection

The foundation of this research rests on a detailed dataset of green bond issuers covering the period from January 1, 2013, to January 1, 2023. These ten years are intentionally selected to enable an in-depth exploration of the impacts of green bond issuance on energy efficiency outcomes, considering the time required to manifest observable effects post-issuance. The dataset, sourced from FactSet, focuses exclusively on green bonds issued within Europe, reflecting the region's leadership in sustainability and the green bond market.

To ensure the dataset's relevance to the research objectives of examining corporate finance and environmental sustainability, issuances by government or agency entities are excluded. This filtration guarantees the dataset's focus on corporate issuers, aligning with the study's aim to scrutinize the intersections between corporate green bonds and energy efficiency.

Moreover, only first-time issuances are utilized in this study due to their relevance when examining corporate green bonds, as highlighted by Flammer (2021). Flammer's research demonstrates that investors respond more positively to the announcement of green bond issuances from first-time issuers than to repeated issuers. This positive response is accompanied by significant improvements in the issuers' environmental performance, including higher environmental ratings and lower CO_2 emissions. Furthermore, first-time issuers attract increased ownership by long-term and green investors, indicating a solid market validation of their commitment to sustainability. These factors make first-time issuances a crucial focus for understanding the impact of green bond financing on corporate energy efficiency.

Adopting Fan et al. (2017) methodology, this study applies a sectoral analysis to highlight industries with significant energy consumption and carbon emissions. These sectors are crucial for assessing the potential of green bonds in fostering energy efficiency and reducing carbon footprints. As highlighted by Jin & Wu (2022) and Liu, Huang & Chen (2019), the Information and Technology sector is also energy intensive. This study, therefore, also includes this sector to expand its dataset. The sectors selected for detailed analysis include:

- Industrial Services: contract Drilling, Engineering and construction, Environmental Services, Oil and gas Pipelines, and Oilfield Services/Equipment.
- Non-Energy Minerals: Aluminum, Construction Materials, Steel.
- Transportation: Air Freight/Couriers, Airlines, Marine Shipping, Other Transportation, Railroads, Trucking.
- Utilities: Electric Utilities, Gas Distributors, Water Utilities.
- Technology and Information Services: Data Processing Services, Information Technology Services, Internet Software/Services, Packaged Software.
- Other Sectors: Alternative Power Generation, Forest Products, Other Metals/Minerals.

This sector-specific approach mirrors Fan et al.'s (2017) strategy, focusing on industries essential for energy conservation and emissions reduction efforts. The chosen sectors are pivotal within the industrial economy for their substantial energy usage and emissions output, making them prime candidates for investigating energy efficiency improvements.

The dataset sourced from Factset includes 67 first-time green bond issuers and 117 first-time conventional bond issuers, which form the empirical basis for this study. By examining these issuers and their bond issues, the research aims to elucidate the relationship between green bond financing and corporate energy efficiency strategies within the EU.

Energy Efficiency Measurement

The measurement of energy efficiency encompasses a range of indicators, from simple metrics like energy intensity to complex indices such as the total factor energy efficiency index, which may be calculated using nonparametric or parametric frontier techniques (Wang et al., 2017). For its accessibility and policy relevance, this study opts for the energy intensity measure advocated by Fan et al. (2017). Energy intensity, understood here as the ratio of total energy consumption to operating revenue, offers a straightforward metric to evaluate changes in energy efficiency by comparing pre- and post-green bond issuance energy use against generated revenue. This approach yields a precise, quantifiable measure of energy efficiency alterations directly associated with green bond activities.

Control Variables

To refine the analysis, this study introduces several control variables, in line with Yeow & Ng (2021), to account for external factors potentially influencing the dependent variable energy efficiency. These include:

- Firm Size: Acknowledging economies of scale in green investments, prior research suggests a positive correlation between firm size and environmental outcomes (Elsayed & Paton, 2005; Ong et al., 2016). Larger firms may possess more resources to allocate towards energy efficiency projects.
- Equity Multiplier: These metrics indicate a firm's financial structure and help control for differences in access to capital that could impact investment in energy efficiency (Flammer, 2021).
- Operating Margin: This profitability indicator can influence a firm's capacity and propensity to invest in energy-efficient technologies and practices.
- Asset Turnover: This ratio reflects operational efficiency and measures how effectively a firm uses its assets to generate revenue, which can indirectly relate to energy usage efficiency (Yeow & Ng, 2021)

- GDP: To adjust for macroeconomic influences, the GDP of the respective countries is included as a country-level control, recognizing the economic backdrop's role in shaping corporate energy efficiency initiatives (Tan et al., 2022).

Table 1. Overview of the Control Variables

Variable	Variable name	Explanation
Size	Firm Size	Natural logarithm of the company's total assets
EM	Equity Multiplier	Total assets divided by total equity
OM	Operating Margin	Operating income divided by net sales
AT	Asset Turnover	Net sales divided by total assets
GDP	GDP	Gross Domestic Product of the company's home country

The control variables are all measured end of the fiscal year and will be gathered using Refinitiv Eikon, supplemented with manual searches of public financial documents for each firm involved in the study. This comprehensive approach ensures the accuracy and completeness of the data necessary for evaluating the impact of green bond issuance on energy efficiency.

Methodology

Propensity Score Matching (PSM)

This study aims to investigate the impact of green bond issuance on corporate energy efficiency within the European Union over a decade, from January 1, 2013, to January 1, 2023. Since decisions to issue green bonds are not made randomly, establishing a robust methodological framework is essential to explore the causal relationships between green bond issuance and its effects on energy efficiency.

PSM is included in our research methodology to address potential biases arising from the quasi-experimental nature of green bond issuance. As Dehejia and Wahba (2002) describe, PSM is a technique used in observational studies to correct biases associated with self-selection. By matching firms based on observable characteristics, PSM aims to mimic a randomized trial, creating comparable groups of firms that have issued green bonds (treatment group) and those that have not (control group), thereby effectively minimizing selection bias inherent in non-randomized settings.

The PSM employs a logistic regression model to calculate propensity scores, utilizing control variables such as firm size, equity multiplier, operating margin, asset turnover, and GDP. These variables are selected for their dual role in predicting the likelihood of a firm issuing a green bond and adjusting for covariates that influence the outcome variable. By integrating these control variables, the PSM approach reduces bias and enhances the balance between treated and control groups, making causal inferences more reliable. This method ensures a more accurate estimation of treatment effects by aligning the characteristics of firms more closely across groups, thereby improving the robustness of the study's results (Rubin & Thomas, 2000).

To eliminate bias and ensure high-quality matches, the nearest neighbour matching algorithm pairs firms with the closest propensity scores within a predefined calliper width. The efficacy of this strategy in reducing selection bias and providing accurate estimates of treatment effects is supported by findings from Yeow & Ng (2021), Sebastiani (2019), and Zhou and Cui (2019).

Linear Regression

A Linear Regression analysis is employed to investigate Hypothesis 2, which posits that the impact of green bond issuance on energy efficiency varies significantly across different industries within the EU. This approach aligns with the study by Dan and Tiron-Tudor (2021), which performed a similar study on green bonds in the EU using a Linear Regression. The regression model includes industry-specific dummy variables to capture the differential effects of green bond issuance on energy efficiency across various industries. This methodological approach is particularly suitable for Hypothesis 2 as it allows for isolating the effect of green bond issuance on energy efficiency for each industry while controlling for firm-level characteristics and macroeconomic factors.

Difference-in-Difference (DID)

The next phase of this study involves a DID analysis to investigate Hypothesis 1. The DID method is employed to quantify the effect of green bond issuance on corporate energy efficiency. This analysis operates under the premise that, while not all firms issue green bonds, those that do may experience differential effects regarding energy efficiency outcomes compared to those that do not.

The DID approach estimates the causal effect of green bond issuance by leveraging temporal variations in treatment across similar entities. By comparing the changes in outcomes over time between a treatment group (companies that have issued green bonds) and a control group (companies similar in financial ratios but have not issued green bonds), the DID model isolates the impact of green bonds from other confounding factors. This method accounts for common trends affecting both groups, thus providing a robust framework for assessing the specific impacts of green bonds on energy efficiency.

As noted by Wu et al. (2022), the DID model can effectively evaluate the implementation effect of green bonds, thus alleviating the endogenous problem of the model. This further validates the choice of DID following PSM, as it enhances the analysis by addressing potential endogeneity issues, making it particularly effective for this longitudinal study. Following the initial PSM, the rationale for selecting the DID model is its specificity in handling data that involves observations before and after intervention in two groups. This setup is ideal for longitudinal analysis and is particularly effective in distinguishing the effect of green bonds from other variables that might influence corporate performance. The DID method has been validated in related financial studies such as those by Tang & Zhang (2020), Flammer (2021), Sebastiani (2019), and Zhou and Cui (2019), which have explored the impacts of green bonds on various corporate outcomes, reinforcing the suitability of this approach for the current research.

Regression and DID Models

Model for Hypothesis 1

To test the first hypothesis, which posits that corporations in energy-intensive industries issuing green bonds will show significant improvements in energy efficiency metrics post-issuance compared to non-issuing counterparts, the analytical model is defined as:

$$Energy\ Efficiency\ i\ t = \alpha + \beta 1(\ GreenBondIssuance\ i) + \beta 2(PostIssuePeriod\ t\ i) + \beta 3\ \ (GreenBondIssuance\ i * PostIssuePeriod\ t) + \sum \gamma k(ControlVariables\ i\ t) + \mu i + \lambda t + \epsilon it$$

Model for Hypothesis 2

To test the second hypothesis, which posits that the impact of green bond issuance on energy efficiency varies significantly across different industries within the EU, the analytical model is defined as follows:

$$Energy\ Efficiency\ it\ = \alpha\ +\ \beta 1(Industry\ it) + \sum \gamma k(ControlVariables\ it) +\ \mu i + \lambda t\ +\ \epsilon it$$

Table 2. Explanation of the Variables in the Model

Variable	Explanation
EnergyEfficiency *it*	Energy efficiency of firm i in year t, measured as the ratio of total energy use to operating revenue, indicating energy efficiency improvements
GreenBondIssuance *i*:	A binary variable indicating whether firm *i* has issued a green bond within the study period.

PostIssuePeriod t	A binary variable marking the years following the issuance of a green bond.
GreenBondIssuance i×PostIssuePeriod t	An interaction term to capture the differential impact of green bond issuance on energy efficiency post-issuance.
Industry j×GreenBondIssuance i×PostIssuePeriod t	Interaction terms for each industry j with the issuance and post-issuance period indicators, allowing the model to detect differential impacts across industries
δ j	Coefficients for the triple interaction terms, key for identifying industry-specific impacts on energy efficiency
ControlVariablesit	Includes firm size, financial health indicators like equity multiplier and operating margin, GDP
μi and λt	Firm-specific and year-specific fixed effects, respectively, to control for unobserved heterogeneity.
ϵit	The error term

Results

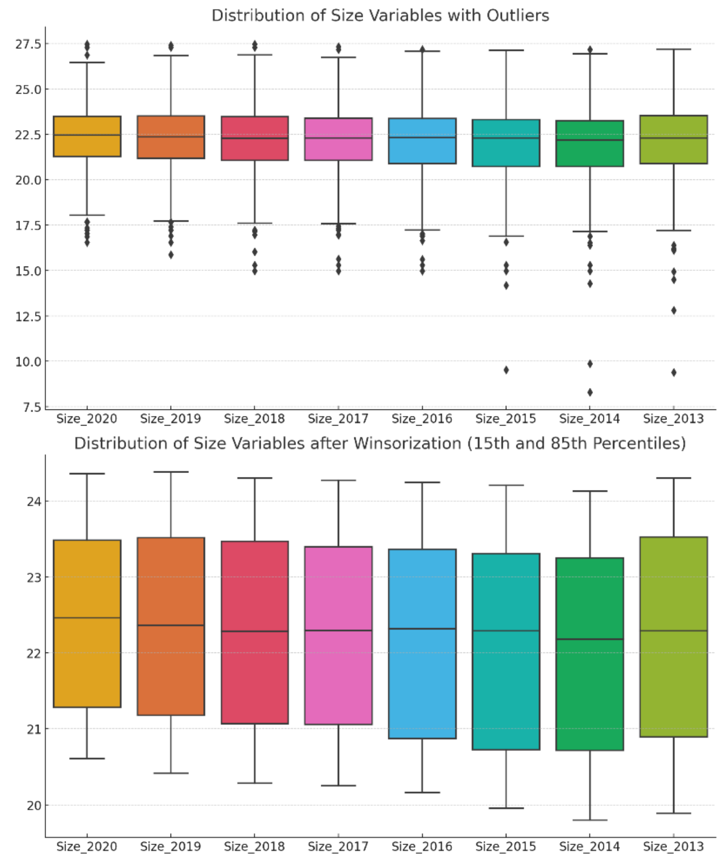
Propensity Score Matching

Winsorization

In analyzing the Size variables, it was apparent that the dataset appeared to be skewed due to the presence of significant high-side outliers. To address this skewness and create a more workable dataset for the PSM, winsorization was applied at the 15th and 85th percentiles. This process effectively reduces the influence of extreme values by capping the data within these bounds, leading to a more normalized and representative distribution. Each variable has been renamed by adding a __w to indicate the winsorized values resulting in: EE_w (Energy Efficiency), Size_w (Firm Size), EM_w (Equity Multiplier), AT_w (Asset Turnover), OM_w (Operating Margin), and GDP_w (Gross Domestic Product).

The Electric Utilities sector was found to have the most high-side outliers. These outliers skew the distribution and highlight the dominance of these companies within the industry. In addition to high-side outliers, several low-side outliers were identified across various industries, indicating companies with significantly smaller Size values. Notable low-side outliers include companies in Construction Materials, Gas Distributors, Alternative Power Generation, and Water Utilities, highlighting the presence of companies with relatively small Size values within these sectors. The resulting boxplots demonstrate that winsorization mitigates the distortion caused by outliers, ensuring the dataset better reflects the overall industry without being unduly influenced by a few large entities.

Figure 1. Boxplot of the Distribution of the Size Variables with and without Outliers



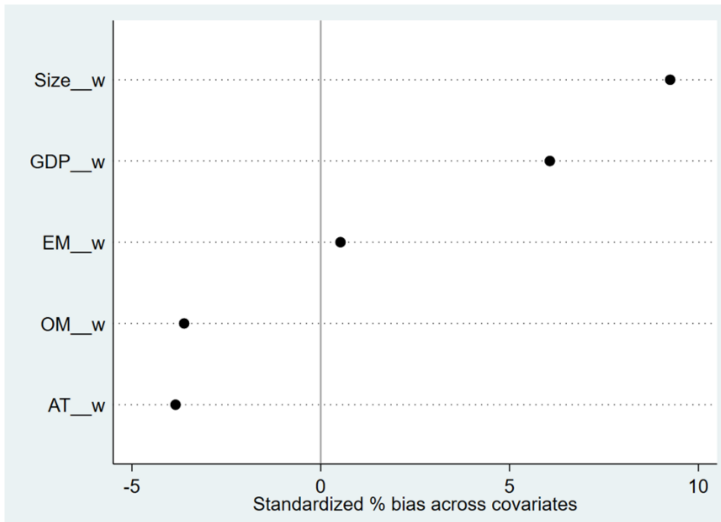
PSM Analysis

Before delving into the descriptive statistics and inferential analyses, it is essential to discuss the initial step of PSM that was undertaken to ensure comparability between the treatment group (companies that issued green bonds) and the control group (companies that did not issue green bonds). Given that decisions to issue green bonds are not made randomly, the PSM process was crucial for reducing selection bias and enhancing the credibility of the causal inferences drawn from this study.

The propensity score for each firm was calculated using a logistic regression model, considering key covariates that influence the likelihood of green bond issuance, such as firm size and financial health. Matching was done using the nearest neighbor method with a caliper, which restricts matches to those within a specified propensity score distance, thereby ensuring that the matched firms were similar in all observed aspects except for the treatment condition.

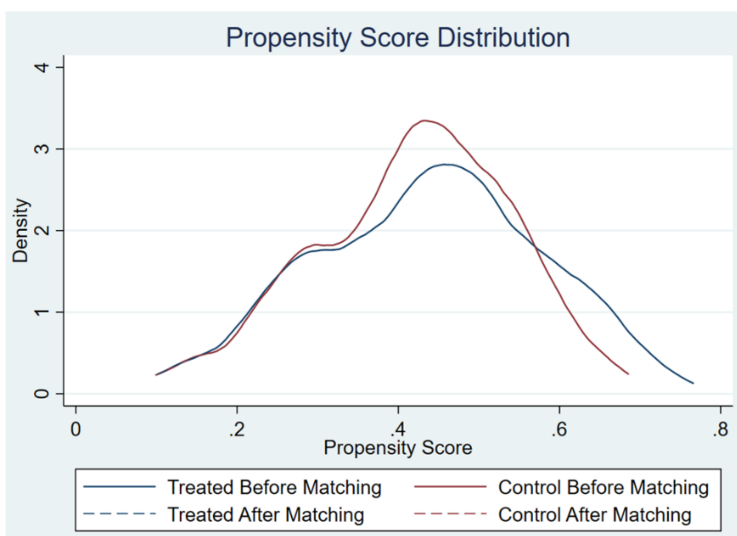
The graph below illustrates the standardized percent bias across covariates before and after matching. As shown, the bias for each covariate is substantially reduced post-matching, falling well within acceptable limits (below 10%), which indicates a well-balanced match between the treatment and control groups.

Figure 2. Standardized Bias Across Covariates for Propensity Score Matching



The propensity score distributions before and after matching are depicted below. These graphs demonstrate that the distribution of scores between the treated and control groups is more similar after matching, indicating effective balancing of the groups. This similarity supports the robustness of the subsequent analyses, as it suggests that the matched groups are statistically comparable.

Figure 3. Propensity Score Distribution Before and After Matching



This carefully matched dataset set the stage for the following detailed analyses, beginning with the descriptive statistics of the key variables involved in assessing the impact of green bond issuance on energy efficiency.

Descriptive Statistics

The analysis of key variables pertinent to green bond issuance and energy efficiency within EU's energy-intensive industries reveals significant variability and industry-specific trends. The average energy efficiency score across the dataset stands at 79.60, but with a high standard deviation of 131.66, indicating considerable disparities in performance among firms. This variability suggests that while some firms exhibit exceptionally high energy efficiency, others lag significantly behind, highlighting the potential for improvement through targeted strategies.

Firm size shows less variability, with an average natural logarithm of total assets at 22.68. The distribution is slightly left-skewed, suggesting that the dataset predominantly comprises larger firms, though it also includes some significantly smaller entities.

The financial leverage, measured by the equity multiplier, averages 13.29, with a right-skewed distribution, indicating that some firms operate with extremely high leverage, potentially impacting their investment capacity in energy-efficient technologies.

Table 3. Summary Statistics of the Used Variables

	N	mean	sd	min	p50	max	skewness	kurtosis
EE__w	1388	79.60279	131.6635	.8005726	11.88751	373.3592	1.578192	3.768023
Size__w	1388	22.60646	1.35712	20.20992	22.78672	24.2996	-.3397358	1.923934
EM__w	1388	13.29822	24.96128	1.989475	3.636855	94.43033	2.658964	8.606545
AT__w	1388	.3885792	.2294236	.1150923	.3580662	.78141	.4215499	1.883367
OM__w	1388	14.91761	10.96498	2.862225	11.54097	35.85362	.6790095	2.191477
GDP__w	1380	1.64e+12	1.04e+12	2.49e+11	1.65e+12	2.98e+12	-.0435575	1.398648

These statistics provide a foundational understanding of the landscape within which green bonds are issued and their potential impact on improving energy efficiency. For more detailed analysis of the summary statistics and further breakdowns by industry and country, please refer to Tables 8 and 9 in Appendix A.

Correlation Analysis

This sub-chapter presents the correlation analysis among key variables involved in the study, which seeks to evaluate the impact of green bond issuance on energy efficiency in EU energy-intensive industries.

Table 4. Correlation Matrix for the Used Variables

	EE__w	Treatm~t	Size__w	EM__w	AT__w	OM__w	GDP__w
EE__w	1.0000						
Treatment	-0.0903***	1.0000					
Size__w	-0.5317***	0.0498*	1.0000				
EM__w	0.0115	0.0051	-0.0249	1.0000			
AT__w	-0.2058***	-0.0194	0.1141***	-0.0476*	1.0000		
OM__w	-0.0931***	-0.0182	-0.0794***	-0.0684**	-0.4987***	1.0000	
GDP__w	-0.1530***	0.0303	0.1048***	0.0561**	0.1765***	-0.0513*	1.0000

The correlation matrix reveals that the relationship between green bond issuance and energy efficiency (EE_w) is weakly negative at -0.0983, suggesting minimal direct influence. Similarly, there's a moderately strong negative correlation of -0.5317 between company size and energy efficiency, indicating that larger companies may be less efficient, likely due to difficulties in scaling energy-saving technologies. The equity multiplier shows an insignificant correlation of 0.0115 with energy efficiency, implying that financial leverage does not directly affect energy efficiency. Asset turnover is significantly negatively correlated at -0.2858 with energy efficiency, suggesting that higher operational activity levels might lead to increased energy consumption. Operating Margin also has a weak negative correlation of -0.0911 with energy efficiency, which might indicate that more profitable operations, associated with higher output, lead to greater energy use. Lastly, a mild negative correlation of -0.1538 between GDP and energy efficiency suggests that larger economic scales may correlate slightly with lower energy efficiency, potentially due to intensified economic activities. This analysis highlights the nuanced interactions between corporate financial health, operational metrics, and macroeconomic factors in shaping energy efficiency outcomes in the context of green financing.

Linear Regression and DID Analysis

Heteroskedasticity & Clustered Standard Errors

To analyze the impact of green bond issuance on energy efficiency, the study employs both regression and DID approaches, incorporating year fixed effects and clustered standard errors at the country level in both analyses. This method accounts for within-country correlation and ensures robust inference, acknowledging that observations within the same country may be correlated due to shared economic, regulatory, and environmental factors. By clustering standard errors at the country level, the standard errors adjust to be more reliable, reflecting the true variability in the data and reducing the risk of Type I errors (false positives) (Cameron & Miller, 2015; Abadie et al., 2023).

Two essential tests for heteroskedasticity were conducted to ensure the reliability of the regression estimates: the Modified Wald test for groupwise heteroskedasticity in the DID model and the Breusch-Pagan test for general heteroskedasticity in the regular regression model. Both tests can be found in Appendix B. The Breusch-Pagan test in Table 10 for the regular regression model revealed significant heteroskedasticity (chi-square statistic of 306.08, p-value of 0.0000). This confirms the presence of heteroskedasticity, justifying the use of clustered standard errors to correct for this issue. Similarly, the Modified Wald test in Table 11 for the DID model indicated significant groupwise heteroskedasticity (chi-square statistic of 1.0e+34, p-value of 0.0000), affirming the necessity of using clustered standard errors. This ensures that the standard errors are robust and the regression estimates are reliable

The results from both tests strongly indicate the presence of heteroskedasticity in the models, making the use of clustered standard errors crucial for ensuring the reliability of the regression estimates. These robustness checks provide confidence in the validity of the analysis, supporting the conclusions regarding the impact of green bond issuance on energy efficiency.

Linear Regression

Table 12 in Appendix C displays the results from the regression analysis examining the impact of various industries on energy efficiency, controlling for factors such as firm size, equity multiplier, asset turnover, and GDP.

The regression analysis reveals significant variations in energy efficiency across different industries within the EU, as indicated by the coefficients for industry dummy variables. For example, industries such as Internet Software/Services (97.7532, p = 0.019) and Information Technology Services (73.2984, p = 0.013) exhibit significant positive impacts on energy efficiency, suggesting these sectors are relatively more energy-efficient compared to the baseline industry. Conversely, industries like Trucking (47.2754, p = 0.131) and Water Utilities (-5.8463, p = 0.888) do not show significant impacts, indicating no substantial difference from the baseline in terms of energy efficiency. Significant positive coefficients for Electric Utilities (61.9833, p = 0.009) and Engineering & Construction (51.3284, p = 0.042) reflect better energy efficiency performance, likely due to stricter regulations and higher investments in energy-efficient technologies. Control variables such as firm size, equity multiplier, asset turnover, and GDP were included in the model, but did not show significant impacts, suggesting these factors might not directly drive energy efficiency improvements in this dataset. Year and country fixed effects were also included to account for unobserved heterogeneity. Overall, the analysis highlights the heterogeneity in energy efficiency performance across industries and underscores the importance of sector-specific strategies and policies to enhance energy efficiency. The significant positive impacts in certain industries suggest that targeted measures and investments can lead to substantial improvements in energy performance.

To ensure the reliability of our regression estimates for the second hypothesis, which examines the differential impact of green bond issuance on energy efficiency across various industries, we assessed multicollinearity using the Variance Inflation Factor (VIF). The mean VIF was 5.61, indicating moderate multicollinearity. This level of multicollinearity is generally acceptable. The individual VIF values for the predictors are presented in Table 13 of Appendix C.

Difference-in-Differences Analysis

Table 5 extends the analysis by incorporating interaction terms to explore the DID analysis, examining how the impact of green bond issuance on energy efficiency evolves over time.

Table 5. Stata Output DID Analysis

VARIABLES	(1) EE__w
o.Treatment	-
time	9.620
	(7.605)
TreatXtime	22.95**
	(8.242)
Size__w	-35.88**
	(13.64)
EM__w	1.224**
	(0.578)
AT__w	-53.06**
	(23.72)
OM__w	-2.621***
	(0.773)
GDP__w	0
	(7.62e-11)
Constant	947.1***
	(254.0)
Observations	1,380
Number of Issuer_num	183
R-squared	0.141
Year FE	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5 shows that the Treatment variable was omitted due to collinearity, a common issue in DID models with fixed effects (De Chaisemartin & D'haultfœuille, 2023). However, the interaction term (TreatXtime) captures the differential effect of green bond issuance over time, providing the key insight into the impact of the treatment.

Furthermore, the results of the DID analysis, indicate that the interaction term is positive and significant ($\beta = 22.95$, $p < 0.01$), demonstrating that the issuance of green bonds significantly improves energy efficiency over time. Larger firms tend to have lower energy efficiency (β = -35.88, $p < 0.01$). Additionally, higher asset turnover and operating margin are associated with lower energy efficiency, with coefficients of -53.06 ($p < 0.1$) and -2.621 ($p < 0.05$), respectively. The model includes year fixed effects to control for unobserved heterogeneity across different time periods. Despite the moderate multicollinearity indicated by a VIF of 3.71 in Table 13 in Appendix C, the regression results remain robust and reliable, and the model explains 14.41% of the variability in energy efficiency (R-squared = 0.1441).

The significant interaction term between treatment and time indicates that over time, the effect of green bond issuance becomes positive on energy efficiency. This suggests that green bonds, while not immediately impactful, lays the groundwork for sustainable practices that gradually lead to enhanced energy efficiency across various industries and regions.

Robustness Tests

The placebo test in Table 6 introduced a pseudo-treatment to validate the causal inference from the main analysis. The coefficient for the placebo interaction term was -2.8143 with a p-value of 0.743, indicating no significant impact. This confirms that the main results are not due to random chance, reinforcing their robustness by showing no artificial effects where none were expected. The parallel trend test in Table 7 checked if pre-treatment trends in energy efficiency were similar between treatment and control groups. The non-significant coefficients for pre-treatment years (p-values > 0.05) suggest parallel trends before the treatment. This validates the DID methodology, confirming that the energy efficiency trends would have been similar without the treatment, supporting the reliability of the causal inferences.

Table 6. Stata Output of Placebo Test

Fixed-effects (within) regression	Number of obs = 1,388
Group variable: Issuer_num	Number of groups = 183
R-sq:	Obs per group:
within = 0.0186	min = 1
between = 0.0015	avg = 7.6
overall = 0.0052	max = 10
	F(10,1195) = 2.26
corr(u_i, Xb) = -0.0064	Prob > F = 0.0127

EE__w	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
placebo_treatXtime	-2.8143	8.577289	-0.33	0.743	-19.64252	14.01392
Year						
2014	-13.40235	9.610442	-1.39	0.163	-32.25756	5.452873
2015	-17.24567	9.588435	-1.80	0.072	-36.05772	1.566367
2016	-25.60157	9.630069	-2.66	0.008	-44.4953	-6.707847
2017	-31.47197	9.581261	-3.28	0.001	-50.26993	-12.674
2018	-26.38358	10.56844	-2.50	0.013	-47.11834	-5.648814
2019	-27.878	10.59515	-2.63	0.009	-48.66515	-7.090838
2020	-32.35263	10.50696	-3.08	0.002	-52.96676	-11.73849
2021	-6.302076	10.73251	-0.59	0.557	-27.35873	14.75458
2022	-23.19111	10.67074	-2.17	0.030	-44.12658	-2.255642
_cons	100.7049	8.108398	12.42	0.000	84.79664	116.6132
sigma_u	112.64884					
sigma_e	78.313609					
rho	.6741703	(fraction of variance due to u_i)				

F test that all u_i=0: F(182, 1195) = 14.73 Prob > F = 0.0000

Table 7. Stata Output of Parallel Trend Test

Linear regression	Number of obs = 832
	F(5, 173) = 0.91
	Prob > F = 0.4785
	R-squared = 0.0043
	Root MSE = 133.55

(Std. Err. adjusted for 174 clusters in Issuer_num)

EE__w	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
Year						
2014	-8.98333	9.978185	-0.90	0.369	-28.67799	10.71133
2015	-17.86794	11.7897	-1.52	0.131	-41.13811	5.402229
2016	-23.39574	12.72373	-1.84	0.068	-48.50947	1.717993
2017	-24.5803	12.80514	-1.92	0.057	-49.85472	.6941082
2018	-20.62096	13.82148	-1.49	0.138	-47.90141	6.659488
_cons	98.75237	11.51707	8.57	0.000	76.02031	121.4844

Discussion and Conclusion

Discussion

This thesis critically examined the influence of first-time green bond issuance on energy efficiency within the European Union's energy-intensive industries. The key findings reveal that the issuance of green bonds significantly enhances post-issuance energy efficiency metrics for these corporations compared to their non-issuing peers. Firms that issued green bonds for the first time demonstrated substantial and statistically significant improvements in energy efficiency, affirming the hypothesized role of green bonds in promoting sustainable practices. Specifically, these companies effectively reduced their energy consumption relative to their operational output more than those issuing conventional bonds, highlighting the effectiveness of green bonds in driving energy management and sustainability.

Moreover, the impact of green bonds on energy efficiency varied significantly across different industries. Sectors such as Information Technology Services and Internet Software/Services exhibited notable enhancements in energy efficiency metrics post-issuance, benefiting from their capacity for rapid technological adoption and innovation, which green bond funding can further enhance. Conversely, industries like Trucking and Water Utilities showed negligible or no significant changes in energy efficiency, indicating the complex interplay between industry-specific factors and the effectiveness of green bonds. This variability underscores that while green bonds can be highly effective in some sectors, their impact is less pronounced in others due to structural limitations or differing baseline efficiencies. These findings highlight the importance of considering industry-specific characteristics when evaluating the effectiveness of green bonds and suggest that tailored approaches to green finance are necessary to address the unique challenges and opportunities within different industries.

The research validates core aspects of SRI Theory, particularly integrating financial viability with environmental stewardship. Oehmke & Opp (2020) and Gao et al. (2020) argue for the necessity of such integration, which this study supports by demonstrating how green bonds effectively channel capital towards energy-efficient projects. Applying SRI principles in a focused domain goes beyond general environmental benefits, offering specific evidence that strategic investments via green bonds lead to tangible improvements in energy efficiency.

Furthermore, Porter's Hypothesis (1991) suggests that environmental regulations can spur innovation, leading to competitive advantages and productivity gains. The EU Energy Efficiency Directive exemplifies such environmental regulation, aiming to decouple energy consumption from economic growth. The findings here provide concrete examples of this theory in action, showing that first-time green bond issuance can stimulate significant improvements in energy efficiency within industries particularly receptive to technological innovations and regulatory frameworks like the EU Energy Efficiency Directive. However, the varied impact across different sectors illustrates the context-dependent nature of this hypothesis. This differential impact highlights that the effectiveness of green bonds can vary greatly depending on industry-specific dynamics.

Additionally, the study extends the signalling theory, as discussed by Lyon and Montgomery (2015), Connelly et al. (2011) and Flammer (2021), which posits that green bonds allow companies to commit publicly to environmental sustainability. This research confirms that such signalling is not just symbolic. The tangible improvements in energy efficiency observed post-first-time green bond issuance demonstrate that these financial instruments are substantial actions toward sustainability, aligning closely with the findings of Flammer (2021). This practical demonstration of signalling theory reinforces that green bonds do more than attract eco-conscious investments; they result in measurable operational enhancements.

Implications

The findings of this thesis have significant implications for policymakers, investors, and corporate managers across the EU. For policymakers, the evidence supports the effectiveness of green bonds in advancing energy efficiency within energy-intensive industries. This suggests that enhancing regulatory frameworks and providing incentives for green bond issuance can be a viable strategy to achieve environmental targets. Policymakers might consider developing more targeted green bond standards or tax incentives to encourage investment in underperforming sectors. Investors can leverage these insights to make informed decisions about green investments. The demonstrated link between green bond issuance and improved energy efficiency metrics suggests that green bonds are not only a responsible investment but also potentially profitable, particularly in industries showing the most significant improvements. For corporate managers, this research highlights the value of issuing green bonds to enhance their sustainability profile and operational efficiency. By integrating green bonds into their financing strategies, companies can meet regulatory requirements and potentially gain competitive advantages through reduced energy costs and enhanced corporate reputation.

Future Research

Future research is essential to deepen understanding and broaden the applicability of green bonds' impact on energy efficiency. Long-term studies should assess whether initial improvements are sustained, providing lasting benefits. Including smaller and less transparent firms will offer a more comprehensive view of green bonds' influence across different company sizes. Expanding the geographic scope to compare global contexts will reveal how various regulatory and economic environments affect effectiveness, helping tailor green bond frameworks to regional needs. Detailed, sector-specific analyses will identify best practices and strategies to maximize impact.

Additionally, future research could consider the effects of non-first-time green bond issuances and the differences between first-time and subsequent issuances. Exploring other types of sustainability-oriented bonds, such as social and sustainability bonds, could provide insights into their distinct impacts on corporate practices. Further, examining bonds beyond corporate issuances, such as municipal, sovereign, and treasury bonds, could reveal broader implications for green finance. As the dataset on green bond issuances grows, the empirical analysis will improve, enhancing reliability. Addressing these areas will provide a more nuanced understanding of green bonds' role in promoting energy efficiency and sustainability.

Limitations

This thesis provides valuable insights into how green bonds can enhance energy efficiency, yet it is essential to consider several limitations. The potential influence of unobserved variables specific to different industries or regions not included in the study could skew the results, underscoring the complexity of capturing all factors influencing energy efficiency. Also, focusing predominantly on the European Union may limit the applicability of findings to other regions with differing regulatory and market dynamics, as the EU's unique approach to environmental policies and green finance mechanisms may need to be more directly transferable. Reliance on publicly available data from large firms could introduce a bias toward more transparent companies and overlook smaller, less transparent firms. Additionally, the winsorization of 30% (15th to 85th percentiles) to manage outliers may have removed critical data points, potentially leading to an underestimation or overestimation of green bond effects.

The dataset's small size, consisting of only 67 first-time green bond issuances in energy-intensive industries, also limits the statistical power of the analyses and the generalizability of the findings. Additionally, this study exclusively focused on first-time issuances. It did not consider subsequent issuances, which could provide additional insights into the long-term effects and consistency of green bond impacts. While significant correlations between green bond issuance and improvements in energy efficiency were identified, this should only be interpreted with caution due to the complex interdependencies among the variables involved. Despite these limitations, the study contributes to understanding green bonds' impact on corporate sustainability practices. However, these challenges highlight the need for broader datasets, more diverse regional analyses, and refined methodologies in future research.

Conclusion

This thesis underscores the broader significance of green bonds in fostering sustainable economic growth and corporate responsibility within the EU. The research has demonstrated that first-time green bond issuances significantly enhance energy efficiency in energy-intensive industries, aligning with theoretical frameworks such as SRI Theory, Porter's Hypothesis, and the signalling theory. Specifically, firms that issued green bonds showed substantial improvements in energy efficiency metrics compared to their non-issuing peers. Furthermore, the impact of green bonds on energy efficiency varied significantly across different sectors. These findings emphasize the need for tailored approaches to maximize the impact of green bonds across diverse industrial sectors.

The methodological framework, incorporating PSM, Linear Regression, and DID analyses, enhances the reliability of the findings. PSM minimizes selection bias, while Linear Regression and DID analyses, reinforced by clustered standard errors at the country level, address potential data idiosyncrasies. This clustering, validated by Modified Wald and Breusch-Pagan tests indicating heteroskedasticity, adjusts for within-country correlations, reducing Type I errors. Additionally, placebo tests and parallel time trend analyses further support the reliability of the study, suggesting that the observed effects on energy efficiency are likely attributable to green bond issuance rather than external factors, thereby strengthening the study's conclusions.

As the EU continues to lead global sustainability efforts, the strategic issuance of green bonds represents a commitment to environmental stewardship and a promising path toward a more sustainable economic framework. As green finance grows, so too does the potential for a sustainable future, supported by the strategic issuance of green bonds that promise economic returns and a healthier planet for future generations.

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Appendices

Appendix A

Descriptive Statistics

The mean energy efficiency score is 79.60, with a high standard deviation of 131.66, indicating substantial variability among firms. The distribution's right skewness (skewness = 1.57) suggests that a few firms have exceptionally high energy efficiency scores, likely outliers or sector leaders. The average firm size, represented by the natural logarithm of total assets, is 22.68 with a standard deviation of 1.36, showing less variability than energy efficiency. The slight left skewness (-0.34) indicates that the dataset predominantly includes larger firms, with a few significantly smaller firms.

The equity multiplier, indicating financial leverage, averages at 13.29 with a high standard deviation of 24.95. The right-skewed distribution (skewness = 2.65) highlights that some firms operate with extremely high leverage, which may affect their capacity for investing in energy-efficient technologies. The mean asset turnover ratio is 0.39, with moderate variability (SD = 0.29). The right skewness (1.83) suggests that some firms have exceptionally high asset turnover ratios. The operating margin has a mean of 14.97 and a standard deviation of 19.05, indicating substantial variability. The distribution is left-skewed (-0.67), suggesting that some firms achieve exceptionally high profitability. Reflecting the economic size of the firms' host countries, GDP varies significantly, ranging from 2.49e+11 to 2.98e+12, with an average of 1.64e+12. The slight negative skewness (-0.34) shows that most countries have a higher GDP, with fewer countries at the lower end of the scale.

The dataset includes 1,388 firms from various sectors, with Engineering & Construction, Electric Utilities, and Information Technology Services being the most prevalent, indicating significant activity in energy-intensive industries. In contrast, Air Freight/Couriers and Marine Shipping are least represented, reflecting their smaller sector size or lower engagement with green bond initiatives.

Table 8. Summary Statistics of the Industries in the Dataset

Industry	Freq.	Percent	Cum.
Air Freight/Couriers	10	0.72	0.72
Alternative Power Generation	102	7.35	8.07
Aluminum	22	1.59	9.65
Construction Materials	27	1.95	11.60
Data Processing Services	11	0.79	12.39
Electric Utilities	466	33.57	45.97
Engineering & Construction	237	17.07	63.04
Environmental Services	40	2.88	65.92
Forest Products	13	0.94	66.86
Gas Distributors	83	5.98	72.84
Information Technology Services	51	3.67	76.51
Internet Software/Services	34	2.45	78.96
Marine Shipping	10	0.72	79.68
Oil & Gas Pipelines	17	1.22	80.91
Oilfield Services/Equipment	16	1.15	82.06
Other Metals/Minerals	16	1.15	83.21
Other Transportation	50	3.60	86.82
Packaged Software	62	4.47	91.28
Railroads	50	3.60	94.88
Steel	33	2.38	97.26
Trucking	10	0.72	97.98
Water Utilities	28	2.02	100.00
Total	1,388	100.00	

Germany and France dominate the dataset, representing significant portions due to their large economies and active participation in green financing. In contrast, smaller EU countries like Estonia and Ireland show minimal representation, highlighting disparities in green bond issuance across the region.

Table 9. Summary Statistics of the Countries in the Dataset

Domicile	Freq.	Percent	Cum.
Austria	45	3.24	3.24
Belgium	77	5.55	8.79
Bulgaria	9	0.65	9.44
Czech Republic	21	1.51	10.95
Denmark	20	1.44	12.39
Estonia	2	0.14	12.54
Finland	70	5.04	17.58
France	315	22.69	40.27
Germany	166	11.96	52.23
Greece	17	1.22	53.46
Ireland	1	0.07	53.53
Italy	148	10.66	64.19
Lithuania	10	0.72	64.91
Luxembourg	18	1.30	66.21
Malta	9	0.65	66.86
Netherlands	114	8.21	75.07
Norway	44	3.17	78.24
Poland	10	0.72	78.96
Portugal	12	0.86	79.83
Slovakia	25	1.80	81.63
Spain	148	10.66	92.29
Sweden	28	2.02	94.31
United Kingdom	79	5.69	100.00
Total	1,388	100.00	

Appendix B.

Table 10. Breusch-Pagan Test for Heteroskedasticity in the Regression

```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
         Ho: Constant variance
         Variables: fitted values of EE__w

         chi2(1)      =   306.08
         Prob > chi2  =   0.0000
```

Table 11. Modified Wald Test for Groupwise Heteroskedasticity in the DID

```
Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (183)  =   1.0e+34
Prob>chi2 =      0.0000
```

Appendix C.

Table 12. Regression Stata Output

VARIABLES	(1) EE__w
Alternative Power Generation	81.07***
	(19.34)
Aluminum	47.53
	(66.59)
Construction Materials	67.84**
	(25.24)
Data Processing Services	82.41***
	(23.91)
Electric Utilities	115.5***
	(27.24)
Engineering & Construction	97.38***
	(23.63)
Environmental Services	43.45
	(27.86)
Forest Products	101.0***
	(23.31)
Gas Distributors	78.86*
	(38.53)
Information Technology Services	73.58***
	(20.50)
Internet Software/Services	68.94
	(49.51)
Marine Shipping	60.74***
	(18.21)
Oil & Gas Pipelines	150.0***
	(23.47)
Oilfield Services & Equipment	98.16***
	(30.71)
Other Metals/Minerals	124.3**
	(47.39)
Other Transportation	39.46
	(51.44)
Packaged Software	99.46***
	(29.86)
Railroads	101.0**
	(36.79)
Steel	170.5***
	(37.90)
Trucking	53.04***
	(12.60)
Water Utilities	6.920
	(31.39)
Size__w	-55.34***
	(7.514)
EM__w	-0.125
	(0.199)
AT__w	-152.8***
	(40.61)
OM__w	-3.471***
	(0.848)

Table 13. VIF of Linear Regression

Variable	VIF	1/VIF
TreatXtime	1.11	0.896956
industry_num		
2	10.91	0.091668
3	3.31	0.302195
4	3.80	0.263156
5	2.13	0.469930
6	33.67	0.029699
7	21.85	0.045770
8	5.11	0.195877
9	2.38	0.419659
10	9.50	0.105240
11	6.05	0.165246
12	4.78	0.209162
13	2.03	0.493198
14	2.93	0.341880
15	2.73	0.366334
16	2.78	0.359656
17	6.22	0.160864
18	6.62	0.150994
19	6.25	0.160070
20	4.36	0.229113
21	2.04	0.489799
22	3.89	0.257138
Size__w	1.23	0.815625
EM__w	1.11	0.904173
AT__w	1.96	0.511254
OM__w	1.44	0.696707
GDP__w	1.34	0.744764
Mean VIF	5.61	

Table 14. VIF of DID

Variable	VIF	1/VIF
time	2.73	0.366321
TreatXtime	1.85	0.539396
Size__w	21.62	0.046255
EM__w	1.35	0.743045
AT__w	5.50	0.181913
OM__w	3.80	0.263182
GDP__w	3.73	0.268329
Year		
2014	1.96	0.509683
2015	1.97	0.506779
2016	1.98	0.505166
2017	1.99	0.503307
2018	2.02	0.494177
2019	2.08	0.480067
2020	2.12	0.471373
2021	2.28	0.438884
2022	2.41	0.415222
Mean VIF	3.71	